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Identifying the unique challenges of installing cold ironing at small and medium ports – The case of aberdeen

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ABSTRACT

Emissions from shipping contribute significantly to both climate change and local air pollution. Cold ironing (onshore power supply) reduces emissions while ships are berthed in port by providing power from shore-side electricity rather than onboard auxiliary generators. Previous research has focused on installing the technology in large ports but if policy goals (particularly in the EU) are to be achieved then smaller ports must also install the technology. Therefore, this study examines the feasibility of installing cold ironing in a medium sized port with several small berths, based on the case of Aberdeen.

Vessel call data were analysed to calculate energy demand and a cold ironing system was designed, including separate OPS units for numerous small berths. The total capital cost was £6.6 m (€7.4 m) and the system could save annual emissions of 108 tonnes of NOx, 2.7 tonnes of PM and 4,767 tonnes of CO_2 emissions worth £1.3 m (€1.4 m). Payback scenarios were examined via SCBA, based on the external costs of potential emission savings. In the best case scenario, the substantial external cost benefits would return the system capital and operating costs in only 7.0 years, or 3.5 years if subsidised 50% by the EU. Challenges result from several small berths needing individual OPS units, long cables and cable reel storage, as well as the need for several vessels to install the onboard technology, which must be overcome if ports besides the large cruise and container ports are to install cold ironing.

1. Introduction

The transport sector is responsible for almost a quarter of Europe's greenhouse gas emissions and is the main cause of air pollution in cities. The EU has set a target for 2050 of reducing greenhouse gas emissions from transport to a level at least 60% lower than in 1990. Emissions from shipping already account for 2.8% of global GHG emissions, which is double the level produced by air travel and expected to equal those from road transport by 2020 (Smith et al., 2014). Therefore, it is necessary for the maritime industry to focus on reducing emissions from shipping in an effort to reduce the sector's impact on air pollution.

Over the last decade, much research has focused on reducing emissions from ships at sea, mostly as a result of IMO regulations on cleaner fuel, which have focused on SOx (first through SECA limits of 0.1% sulphur and more recently through a global sulphur limit of 0.5% by 2020), and more recently on NOx. Despite the large contribution of shipping to global GHG emissions, CO_2 targets remain absent. Other methods to reduce shipping emissions include some vessel design improvements also mandated to some extent by the IMO, such as EEDI and SEEMP (Cullinane and Bergqvist, 2014; Lister et al., 2015) and fuel reduction through slow steaming (Cariou, 2011; Zis et al., 2015).

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Table 1
Ports using cold ironing (WPCI, 2017).

Introduced	Port	Country	Introduced	Port	Country
2000	Gothenburg	Sweden	2010	Verko, Karlskrona	Sweden
2000	Zeebrugge	Belgium	2010	Amsterdam	Netherlands
2001	Juneau	USA	2011	Long Beach	USA
2004	Los Angeles	USA	2011	Oslo	Norway
2005	Seattle	USA	2011	Prince Rupert	Canada
2006	Kemi	Finland	2012	Rotterdam	Netherlands
2006	Kotka	Finland	2012	Oakland	USA
2006	Oulu	Finland	2012	Ystad	Sweden
2006	Stockholm	Sweden	2012	Helsinki	Finland
2008	Antwerp	Belgium	2013	Trelleborg	Sweden
2008	Lubeck	Germany	2014	Riga	Latvia
2009	Vancouver	Canada	2015	Bergen	Norway
2010	San Diego	USA	2015	Hamburg	Germany
2010	San Francisco	USA	2015	Civitavecchia	Italy

Vessel emissions in ports are increasingly of concern, especially for SOx, NOx and PM rather than CO_2. The former affect local populations directly while the amount of CO_2 produced in ports is a very small portion of global shipping CO_2. The World Health Organization (WHO) considers air pollution a major environmental risk to health estimating that it results in three million deaths per year (World Health Organisation, 2016). Shipping contributes a significant amount to this, especially in coastal areas. Shipping accounts for approximately 15% of NOx and 5–8% of SOx emissions worldwide (Zis et al. 2016) which both cause serious harm to human health and the environment. Air pollution kills 40,000 people every year in the UK alone and leads to long term illness and death from asthma and other chronic diseases, a significant contributor to which is the shipping sector (Royal College of Physicians, 2016).

Vessel emissions in ports are addressed by methods such as cold ironing, use of LNG and vessel speed reduction in the port (Winkel et al., 2016; Sciberras et al., 2015; Styhre et al., 2017; Winnes et al., 2015). LNG is cheaper than HFO and MGO, has no SOx or PM and much lower NOx but only produces a small CO_2 reduction compared to other fuel. It is a particularly attractive solution to city centre ports with populations nearby. As Winnes et al. (2015: 81) point out: “since the share of total GHG emissions in port areas are low compared to emissions during voyage, a port city might be more benefited from prioritising local issues before global.”

Cold ironing (or onshore power supply (OPS) or shore-side electricity (SSE)) is the process of ships connecting to shore side electricity rather than running their auxiliary generators in order to provide power for hoteling. It has been shown to be effective in reducing emissions contributing to air pollution and climate change in countries with a high concentration of renewable energy generation. According to the WPCI (2017), there are only 28 ports in the world with cold ironing installed, which represents how low the takeup has been so far (Table 1). With the exception of Bergen, all are large ports with high total energy demand, which is also in most cases concentrated in a small number of berths, such as a specialised cruise or container terminal, particularly the former as they have higher hoteling requirements than other vessels due to the number of passengers staying on board. Moreover, all of these projects have been completed with external support in countries where ambitious environmental targets have meant that funding has been available.

The technology still has many operational challenges, especially for ports with several small berths and a wide variety of vessel types which may be reluctant to install the required connections on their vessels. If this technology is to have a significant role in decarbonising the maritime industry it must also be installed in smaller ports and used by many different vessels. The Scottish Government has pledged to support Scottish port authorities in implementing emission abatement technologies including cold ironing. This study aims to set out the level of support required in order to implement this, as well as identifying the unique challenges faced by small and medium ports.

Some high level studies have determined the overall potential for cold ironing, but these must be complemented by case studies in order to understand the practical challenges of designing the systems. There have been a small number so far, with only one on small ports. This paper will examine not just the total energy demand, system costs and emission savings, but will also examine the practical challenges of system design, based on several small berths and a variation of vessel type. The following section reviews the literature regarding policy and regulation for cold ironing and then identifies and discusses the system design issues raised in previous studies. Section 3 presents the Social Cost Benefit Analysis (SCBA) methodology. Section 4 analyses the data on energy demand, presents the system design, calculates costs and finally develops several scenarios for analysis. Section 5 concludes with generalisations to other small and medium ports.

2. Literature review

2.1. National and international policy and regulation for cold ironing

The International Maritime Organization (IMO) is the maritime branch of the United Nations with the “Responsibility for the safety and security of shipping and the prevention of marine pollution by ships.” (International Maritime Organisation, 2017). The

IMO has developed and maintained the regulatory framework for the shipping industry since 1958. The International Convention for the Prevention of Pollution from Ships (MARPOL) was adopted in 1973 by the IMO. Its purpose was to establish a global standard to prevent pollution of the marine environment by ships from operational or accidental causes. The original annexes focused only on preventing pollution to the marine environment. MARPOL has been updated regularly since then and in 2005 MARPOL Annex VI came into force with the aim of preventing air pollution from ships. Its main focus was on reducing air pollution by placing a limit on NOx, SOx and PM emissions from fuel combustion. Annex VI was revised and an amendment came into force in 2010 with an aim to progressively impose more stringent limits and introduce emission control areas (ECA). The ECAs are located in the North Sea, the Baltic Sea, the North America Area and the United States Caribbean area. The amendment aims to reduce the sulphur cap in fuel from 3.5% to 0.5% by 2020. In ECAs the limit was reduced to 0.1% in 2015. The revised annex also imposed tighter restrictions on NOx by introducing regulation 13. This imposes NOx restrictions on ships depending on when they were built by separating vessels into three categories; Tier I, Tier II and Tier III. The introduction of the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP) was agreed in 2011 by the IMO's Marine Environment Protection Committee (MEPC) conference and adopted into MARPOL Annex VI. It requires that certain new ships must adhere to the EEDI and all ships to the SEEMP.

All nations must adhere to the minimum standards of legislation set out by the IMO. However, more stringent regulations can be imposed. The European Union (EU) has ambitious environmental targets and this is also true with regards to their maritime policy. In 2005 the Directive 2005/33/EC was published which defined emission control areas in the English Channel, North Sea and the Baltic Sea. In these areas, a sulphur cap of 1.5% was set and ships at anchorage or in an EU port were required to use fuel with 0.1% sulphur. These regulations were much tighter than the MARPOL Annex VI regulations at the time. Directive 2012/33/EU set out further restrictions on sulphur content of fuels in line with the revised MARPOL Annex VI and discussed the possibility of extending ECAs. It also highlighted concerns with air pollution in ports and recommended that: "Member States should encourage the use of shore-side electricity, as the electricity for present-day ships is usually provided by auxiliary engines." In 2014 this went further as the European Union approved Directive 2014/94/EU on the deployment of Alternative Fuel Infrastructures. This stated that: "Member States shall ensure that the need for shore-side electricity supply for inland waterway vessels and sea-going ships in maritime and inland ports is assessed in their national policy frameworks. Such shore-side electricity supply shall be installed as a priority in ports of the TEN-T Core Network, and in other ports, by 31 December 2025, unless there is no demand and the costs are disproportionate to the benefits, including environmental benefits" (European Commission, 2014). It also encourages transitioning to alternative fuels and allows for state aid in implementing emission abatement technologies.

In the United Kingdom it has been estimated that the total annual cost of air pollution could be as much as £54 billion. The health problems resulting from exposure to air pollution also have a high cost to society and business. In the UK, these health costs add up to more than £20 billion every year (Royal College of Physicians, 2016). The UK has been heavily criticized by the EU, the UN and the WHO for failing to tackle air pollution with the EU limits on air pollution regularly breached in the UK (The Guardian, 2017). Emissions from shipping contribute to this.

The shipping industry in the UK is regulated by the Maritime and Coastguard Agency (MCA). They are responsible for implementing IMO legislation such as MARPOL and any additional measures set out by the EU and UK Government. With the United Kingdom set to leave the European Union it is unclear if the UK will continue to implement the EU directives or if they will only comply with the IMO legislation. The UK has also been less enthusiastic than the EU on the subject of shore power. The Government has discussed cold ironing in their port management review but many are sceptical about the effectiveness of the technology as a method of reducing emissions (Gibbs et al., 2014).

The Scottish Government has ambitious environmental targets. They aim to produce 100% of electricity from renewable sources by 2020. By the end of 2015 the target of 50% was passed, with renewables generating the equivalent of 59.4% of Scotland's electricity requirements (Scottish Government, 2017). The Scottish Government have also funded projects which aim to reduce emissions from shipping. In 2014 Caledonian Maritime Assets Ltd (CMAL), a company owned by the Scottish Government, built three commercial hybrid ferries. These vessels use batteries in tandem with diesel electric engines. These batteries are charged overnight using onshore power. The Scottish Government has aimed to drastically reduce emissions from shipping in Scottish waters. It estimated that in 2014 shipping accounted for 11% of total transport emissions. It found that emissions had fallen from 2.6 $MtCO_2e$ in 1990 to 1.4 $MtCO_2e$ in 2014 (Fig. 1). While emissions from international shipping have fluctuated, emissions from domestic shipping have been reducing steadily.

The Government targets an annual abatement of approximately 2.5 MtCO2e by 2035 from all transport in Scotland. They expect the shipping industry to play a role in this with an expected 35% improvement in the efficiency of new ships by 2035. These include hybrid and gas-powered engines, battery-electric engines and aero foil hulls. Recently in the Government's Energy Strategy report (Scottish Government, 2017) they pledged to work with port authorities to identify the potential costs and benefits of cold ironing and other low emission measures to ship owners and operators, a policy encouraged by the European Union.

2.2. Cold ironing or onshore power supply (OPS)

2.2.1. Potential for cold ironing and general issues

Davarzani, et al. (2016) found that academic research of sustainability in ports has increased noticeably since 2006 as the maritime industry has begun to focus on environmental improvements. The maritime industry had been criticised for its lack of action with Gilbert et al. (2014: 447) noting that "Progress toward decarbonizing shipping has been slow compared with other sectors". The research has focused on emissions from harbour activity, the external cost of these emissions and potential abatement methods. Cold ironing is one of the methods most discussed.

Fig. 1. Emissions from shipping in Scotland (Scottish Government, 2017).

Research on individual ports has concentrated on high voltage shore connections for large vessels such as cruise liners and cargo ships. The consensus is that cold ironing is an effective method of reducing harmful emissions and, although expensive, considerable health savings can be achieved. Winkel et al. (2016) estimated that, if all ports in Europe were to use shore power, in 2020 an estimated €2.94 billion of health costs could be saved with a potential reduction of carbon emissions of 800,000 tons. Vaishnav et al. (2016) found that $70–150 million could be saved on health costs by retrofitting OPS equipment to a quarter to two-thirds of all vessels calling at US ports. They acknowledged that this could result in private losses for operators but policy makers could intervene in order to balance the costs for ships and ports as this would result in a net societal gain.

The papers focusing on policy discuss international policies and incentives to increase the uptake in emission abatement technologies. Some of these papers are already outdated with Arduino et al. (2011) stating that "There is still the presence of several barriers such as the costs (energy cost and infrastructure cost), the lack of standardization for the equipment, and the lack of European legislation." As discussed in the next section, international standards have been published and the EU has issued directives to encourage the uptake of cold ironing, including Directive 2003/96/EC which allows ports to apply for a reduced rate of tax to electricity directly provided to vessels at berth using shore power, but it may also be necessary for ships to pay for the transmission and conversion losses in the system which are estimated at 10% (Zis et al., 2016).

One challenge of using cold ironing is the air pollution produced from national electricity grids. To ensure the projects are as environmentally effective as possible, some studies have focused on including renewable generation as part of a cold ironing project. For example, Kotrikla et al. (2017) designed a hybrid system comprising of four 1.5 MW wind turbines combined with 5 MW photovoltaics to produce all the electricity required for the project, and Ballini and Bozzo (2015b) explored the possibility of offshore wind turbines providing electricity to ships at anchor. Recent research focusing on technical aspects of shore power technology has moved beyond the basic operation and advanced to discussing topics such as integrating OPS into the smart grid (Yiğit et al., 2016), reducing losses from shore power systems (Coppola et al., 2016) and combining shore power with storage devices and auxiliary drives to improve the efficiency of vessels (Sciberras et al., 2017). Sciberras et al. (2017) discuss the use of cold ironing for charging ship batteries as well as running the auxiliary engines in port. With an increasing trend for diversifying onboard power sources, this provides cold ironing with a greater customer base thus increases its attractiveness for ports. This would be particularly relevant for the vessel profile in Aberdeen with many offshore supply vessels (OSVs) which are well suited to combining batteries with combustion engines (Lindstad et al., 2017).

There have been only a handful of case studies of individual ports in the literature, which is strange as the high level studies must be complemented by case studies in order to understand the practical challenges of designing the systems. Ballini and Bozzo (2015a) analysed the potential for installing cold ironing at the port of Copenhagen. They found that if 60% of the cruise ships used cold ironing, they could save the equivalent of €2.8 m of external costs annually, but the total cost of the installation would cost €37 m. Tseng and Pilcher (2015) examine the trade-off between fuel and electricity costs and emission savings by using OPS in a container terminal, while other papers focus on particular factors such as the environmental impact or technical design. Only one published case study has been on small ports: Kotrikla et al. (2017) calculated the energy demand and hence potential emissions savings at the port of Mytilene in Lesvos, according to a different range of energy mixes. However, the authors did not calculate the cost-benefit of the installation itself, which is obviously significant and more so for smaller ports with lower financial resources. This paper aims to fill this gap in the literature by determining not just the emissions savings and contribution to social and environmental benefits, but the cost of the system and the best way to design it for a small-medium port with several small berths.

2.2.2. System design

The system design can be broken into several sections:

- Main incoming station: A connection is made to the national grid carrying high voltage levels of electricity to a local substation, where the voltage is stepped down to a lower level by a transformer. It may also be necessary for power conversion to take place here as it is common for the shore-side frequency and the frequency of the ship to differ.
- Power cables: high voltage cables deliver the power from the sub-station to the shore-side substation at the port terminal.
- Shore-side substation: Here the voltage is reduced further.
- Berth: Cables are installed underground and connected to a cable reel system to avoid handling of high voltages. A davit is used to raise and lower the cable to the vessel.
- Onboard installation: The cable management system is used to connect the cable to a socket onboard the vessel. The power is then fed to a final step-down transformer where the voltage is converted to the level required onboard the vessel.

One of the main challenges with implementing cold ironing had been the lack of international standards for the technology. Different ships of different sizes and functions use different operating voltages and frequencies which are often different to the electrical characteristics of the grid of the port country. This was frequently one of the main deciding factors cited in feasibility studies for ports and shipping companies which prevented them adopting the technology (Yuri Khersonsky, 2007). When the uptake of shore power in the USA and Europe increased there was pressure from various organisations for an international standard to be developed. In 2012 the first international standard for shore power was published, the 80005-1: Utility Connections in Ports - Part 1: High Voltage Shore Connection (HVSC). This was a joint publication by the International Organization for Standardization (ISO), the International Electro-Technical Commission (IEC) and the Institute of Electrical and Electronics Engineers (IEEE). These three bodies are responsible for developing standards for the electrical industry around the world.

One of the biggest challenges is the system design. Coppola et al. (2016: 817) point out that “from a technical point of view … the most critical issue in connecting the vessel electrical system to the main grid is due to the difference between their rated voltages and frequencies.” They added that the two main issues are the power quality and safety issues. Sciberras et al. (2015) analysed the electrical characteristics of a cold ironing system, applied to a harbour in northwest Spain, with a five RoRo berth ferry terminal serving a “range of 50/60 Hz ships with a spread of electrical power demands from around 300 kV A to 1.2 MV A.” (p33). They discuss the published standards and possible topologies, for example, “whether a single frequency converter is centrally located to provide 50/60 Hz of whether a distributed topology is more suited, with a converter for each connection.” (p32). In their system, “the central frequency converter supplies a double busbar arrangement which can be used to selectively provide either 50 Hz or 60 Hz to the berths, as required.” (p34)

3. Methodology

This study applies a mixed methodology, using quantitative methods to calculate the energy demand, cost and the value of emissions savings through a traditional SCBA, complemented by qualitative research based on expert interviews to produce the best system design to meet the particularly challenging needs of a small to medium port. Expert interviews will also allow triangulation of both sets of data to ensure the validity of the calculations. The port of Aberdeen was chosen as this is a busy medium sized port which is situated in a city centre and has a mix of large (cruise) and small (offshore support) vessels.

Following the methodologies of previous papers cited in the preceding section, the first step is to identify the source of energy demand and calculate total requirement per berth, as well as identifying voltage and frequency requirements for the vessel profiles. Then the system must be designed to deliver that quantity of energy to each location when required, including scaling up and down, cable supply and storage. Vessel call data for Aberdeen Harbour will be used to determine the type of vessels using the port and the number of vessel visits, while online sources of vessel profiles and direct contact of shipping companies will be used to calculate the expected energy demand and voltage and frequency requirements. Different configurations will be analysed to determine the most efficient, practical and cost-effective system design. Different configurations will be explored using calculations and ERACS software to determine the most effective option. Once a detailed design of the project has been completed, including all the necessary components, industry experts from ABB, an electrical company specializing in shore power technology, and Scottish and Southern Energy (SSE), the district network operator, will be consulted in order to obtain costs as well as to confirm the “real world” feasibility of the project. Once this is done, the system cost can be calculated.

The second step is to calculate the emissions savings using emission factors from government sources and previous academic research, including different energy mixes from the grid generation. The external costs of these emissions will then be calculated using figures set out by the UK Government. These values can be set against the system costs to produce various scenarios and subsidy options, compared through SCBA as used by previous authors. The analysis calculates both the undiscounted payback period and the NPV based on the standard UK discount rate of 3.5% with two time periods of 10 and 25 years.

4. Results

4.1. The case: The port of Aberdeen

Aberdeen is a city situated in the North East of Scotland with a population of 230,350 (Aberdeen City Council, 2015). Since the

discovery of North Sea Oil in the 1970s Aberdeen has been the main oil hub in Europe. Several large oil companies are based in the city, making Aberdeen one of the most affluent areas in the UK. However, a recent drop in the global oil price has led to a downturn in the oil industry. This has badly affected the city with an estimated loss of 65,000 job losses in the oil and gas sector since 2014 (BBC, 2016). Aberdeen is now looking to renewable energy technologies to help it move past its dependency on oil. It aims to establish itself as a hub for offshore wind power. Scotland has some of the best wind conditions in Europe for offshore wind. The technology and expertise in the Oil and Gas sector are also easily transferrable to the offshore renewable industry.

Aberdeen Harbour is one of Britain's oldest businesses having been established in 1136 (Aberdeen Harbour, 2017). Traditionally it was a fishing port but with the discovery of North Sea oil became Europe's main oil hub which has led to it expanding significantly over the years to become one of Scotland's busiest ports. In 2016, the number of vessels using the port was recorded at 6438 with the harbour reporting a turnover of £32,015,000 (Aberdeen Harbour, 2017). The harbour is a trust port which is an independent port created by an act of parliament meaning that it is controlled by an independent board rather than a local authority or private business (Aberdeen Harbour, 2017).

Aberdeen Harbour is situated in the city centre. Air quality in the harbour area is known to be poor. This led to Aberdeen City Council conducting an air quality report for the harbour area (Aberdeen City Council, 2011). As Aberdeen Harbour is in a Sulphur Emission Control Area (ECA), where ships are required to use fuel with maximum 0.1% sulphur content, SOx emissions were not considered in the study. The study found that in the Air Quality Management Area (AQMA),[1] emissions from shipping contributed to exceedances of annual mean air quality objectives. This was estimated to be 9% for NO_2 and 8% for PM_{10} (Aberdeen City Council, 2011). The 10 berths near the AQMA ship emissions that had an impact on air quality are at Regent Quay, Trinity Quay, Jamieson Quay and the Northern Isles Ferry Terminal in close proximity to the city centre. Nine of the ten berths in this area are used by OSVs, while the tenth is used exclusively by two Northlink ferries. The study recommended that although the main focus should be on reducing emissions from road transport it would also be desirable to reduce emissions from shipping in the area. The study also suggested shore power as a possible technology to reduce emissions in the area.

4.2. Data: vessel call analysis and calculation of energy demand

The Northern isles ferry terminal is used by two sister vessels, the MV Hrossey and the MV Hjaltland of Northlink ferries. The ferries are passenger Ro-Ro vessels with a regular route from Aberdeen to Orkney and Shetland. In 2016, the vessels made a combined 358 visits to the terminal. These vessels have operating voltages of 415 V at a frequency of 50 Hz (Table 2).

Offshore support vessels (Supply ships or OSVs) is a term used to group the various types of ships used traditionally for supporting the oil and gas industry. This involves anchor handlers, platform supply vessels, subsea support vessels and standby vessels. Given Aberdeen Harbour's reputation for being the "Oil capital of Europe" it is therefore unsurprising that the majority of marine traffic in Aberdeen comes from offshore support vessels, with these types of vessels accounting for 67% of the total visits in 2016. As mentioned previously the downturn in the oil price has affected the city badly. This has seen the number of supply ships visiting fall in the past number of years. There is no specific information available for the AQMA berths for 2016. However, specific information is given in the Aberdeen Harbour air pollution report (Aberdeen City Council, 2011). It found that for the year 2010, 272 different vessels visited the project area. Table 3 gives a summary of the findings.

Given the number of different OSVs, varying sizes and varying time in port, it is considerably more difficult to design a shore power installation for these vessels than for the ferry terminal. However, this is best approached with the largest vessels in mind. With the information provided it was found that in 2010 for the nine largest ships there was an expected hoteling energy demand of 2955.1 kW with a total energy demand of 1,188,297 kWh for 2010. However, these ships will not all be alongside at the same time. The average expected hoteling energy demand for nine ships in the AQMA is 923.2 kW.

It is unlikely for all 272 vessels to be equipped with shore power connection equipment, which would require significant capital investment from the ship owners. For ships to benefit from the technology they should be using the berths frequently. However, as discussed there is a significant variation in vessels visits and time spent in port (Table 3). In order to calculate a realistic sample, companies with four or more vessels in the AQMA (62% of all the vessels in the area) were investigated as these were expected to have multiple vessels visiting the harbour and thus more likely to install the technology on their vessels (Table 4). One of the main issues with shore power is that different ships use different voltages and frequencies. However, it was found that despite these shipping companies being from different countries all the vessels had operating voltages of either 440 V or 690 V (for diesel electric ships) with a frequency of 60 Hz. These vessels also all used marine gas oil (MGO) for fuel.

Of all 21 vessels that visited the harbour more than 30 times in 2016, they accounted for a total number of 1257 visits, with an average of 60 per year. The data also revealed that the average time spent in port per visit was 28 h 45 min. The average hoteling energy demand was 101.27 kW and the average energy demand was 176,914.52 kWh.

To summarise the energy demand, the ferries have a hoteling energy demand of 488.8 kW while the maximum energy demand from OSVs was found to be 378 kW per vessel. It is possible that the hoteling energy demand could increase above these levels and losses would be expected in the system. However, with a power factor of no less than 0.9 the energy demand would be well below the 1MVA threshold for a high voltage shore connection and a low voltage system is necessary. The system should be designed for a

[1] It is necessary to declare Air Quality Management Areas (AQMAs) when there is an exceedance or expected exceedance of an air quality objective. Once declared, it is the responsibility of the local government to prepare an Air Quality Action Plan (AQAP) within 12 months, which must set out measures in order to meet the air quality objectives.

Table 2
Vessel particulars for ferries and 2016 visits.

Vessel particulars	MV Hrossey	MV Hjaltland
Number of visits	178	180
Total time spent in port (hours)	2032.61	2178.76
Average time in port per visit (hours)	11.42	12.10
Year built	2002	
Gross Tonnage	11,720	
Length Overall X Breadth Extreme (m)	125 × 20.05	
Main power (kW)	21,600	
Auxiliary power (kW)	1880	
Voltage (V)	415	
Frequency (Hz)	50	
Hoteling power demand at 26% (kW)	488.8	
Fuel	Marine Gas Oil (MGO)	

Table 3
Summary of vessels using berths in the AQMA, 2010.

Average time spent in port (h)	177.9 h
Vessel with longest time in AQMA (h)	UOS Endeavour – 1570 h
Vessel with shortest time in AQMA (h)	Boy Gordon – 0.5 h
Average Power demand in AQMA (kW)	102.6 kW
Vessels with highest hoteling power demand (kW)	Maersk Advancer, Maersk Leader, Maersk Trader, Skandia Admiral – 378 kW
Vessel with lowest hoteling power demand (kW)	Grampian Cavalier – 1.6 kW
Total time spent by ships in AQMA (h)	46574.5 h
Total Energy demand in AQMA (kWh)	6,970,701.45 kWh

Table 4
Identified companies.

Company	Country	Number of Vessels in AQMA (2010)	Total Vessel Visits (2016)	Number of Vessels (2016)	Average Number of Visits per Vessel (2016)
Vroon	Netherlands	36	389	43	9.1
North Star Shipping	UK	29	370	35	10.6
Atlantic Offshore	Norway	16	274	9	10.9
Maersk	Denmark	15	153	10	11.6
Gulfmark	UK	10	265	8	32.8
DOF	Norway	10	499	16	31.2
Solstad Farstad	Norway	17	270	17	15.5
Sea Lion	UK	9	6	2	3
Havila	Norway	5	240	7	34.3
E.R. Schifhart	Germany	4	120	6	20
EDDA	Norway	4	153	6	25.5
GOL offshore	India	4	17	1	17
Olympic	Norway	4	42	9	4.8

maximum 1MVA per berth as part of the 80005-3 standard. This is much higher than the average energy demand of 102.6 kW calculated but will allow for fluctuations in energy demand, use by larger vessels and futureproof the installation by having the capacity to supply electric and battery hybrid vessels in the future.

4.3. System design

4.3.1. Voltage and frequency

The project area is approximately 61,300 m^2 (Fig. 2). One of the main issues is that it is difficult to gain access to the inner ships at the upper dock. As part of the 80005-3 international standard for LVSC, it is necessary to have the cable management system on the quayside to gain access to the vessel. It is also necessary for the installation to be designed to cause as little disruption to the port as possible. There is limited space in the project area so the area at Regent Quay West (top left of the figure) has been identified as the best location for any large centralized units which would prevent disruption to other operations in the port. The ferry berth is at the south quay in the figure, while the area for the OSVs consists of nine berths at Regent Quay, Trinity Quay and Jamieson Quay, an area of approximately 20,000 m^2 (three on the north quays and six at the west quay in the figure). However, for the four inner berths (at the left of the figure) it is not possible to provide quayside cable reels as they must be positioned in a way as to allow the cables access to the distribution switchboard onboard the vessel which is situated at the forward end of the ship.

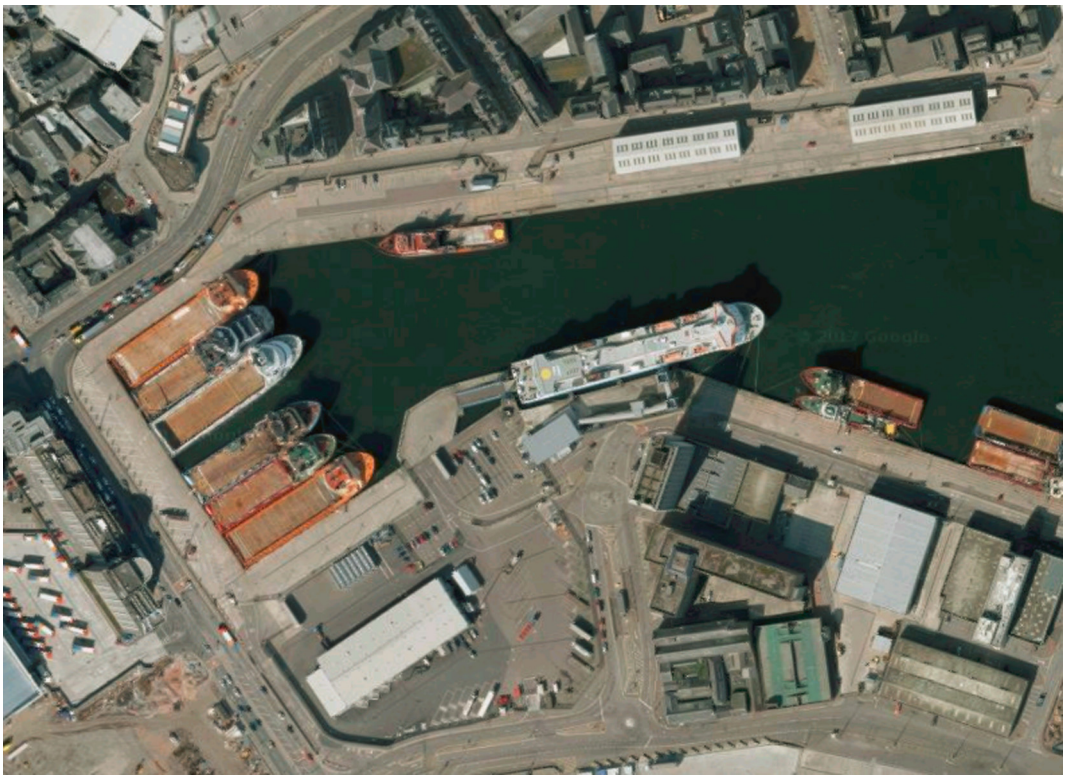

Fig. 2. Port of Aberdeen showing berths in the AQMA. Source: Google maps. Imagery: Infoterra Ltd & Bluesky. Map data: Google.

The district network operator for Aberdeen is Scottish and Southern Energy (SSE). As the current infrastructure in the harbour would not allow for a further 10MVA of energy demand, a new substation would be required. This substation would involve an incoming transmission line at 33 kV with a step-down transformer and the necessary switchgear. The standard shore side voltage will be 400 V at the low voltage level. A shore side isolation transformer is required to provide galvanic separation as part of the 80005-3 international standard for low voltage shore connections. The operating voltage of the ferries is 415 V and the OSVs vary between 440 V for regular ships and 690 V for ships that have diesel electric propulsion, which requires transformers with tap changers which would likely increase the costs of the transformers. This was also the case for the OSV shore power installation in Bergen.

Another factor to consider is the difference in frequency. For the UK grid the frequency is 50 Hz. As the ferries use operating frequencies of 50 Hz there is no need for a frequency converter at that berth. But the OSVs operating frequency was found to be 60 Hz. It is therefore necessary for a frequency converter to be installed. Individual frequency converters can either be installed for each berth or a centralized unit can be provided. It was felt that in this case that despite a possible fault in a centralized frequency converter leading to a total loss of power to all OSV berths, the lack of space in the project area meant that a centralized frequency converter would be the better choice. This would also cost less and be easier to monitor.

4.3.2. Transformers

The first option considered was to step down the voltage at the substation to the standard low voltage level of 400 V as this would allow other low voltage consumers in the area to use the power. This option only considered the five accessible berths for the OSVs and the ferry terminal which would have a separate unit. A load flow simulation was carried out using the ERACS software to give a basic analysis of the values expected in the system, not taking into account losses incurred in the frequency converter, transformers, length of cables, etc. Results show that with the ferry receiving 407 V and the OSVs receiving 434 V that a voltage drop of 2% would be incurred at the berths. It also shows that the low voltage level results in higher current levels from the substation to the berths which would result in significant I^2R heating losses.

After consultation with ABB, it was agreed that it would be possible to supply power to the inner berths at the upper dock. This would involve fitting junction boxes rather than cable reels. Ships can be fitted with extension cables so that the reels can be connected at the aft of the ship, or a containerised cable reel system (developed by Cavotec, a company specialising in cable management systems for OPS) can be lifted on to the deck of vessels in this area. Another ERACS load flow simulation was run, stepping the voltage down to 11 kV at the substation. This resulted in a voltage drop of only 1.3% therefore it was selected.

4.3.3. Central or individual OPS unit

Once it was decided to step down the voltage to 11 kV the next options considered were a centralized unit housing all the

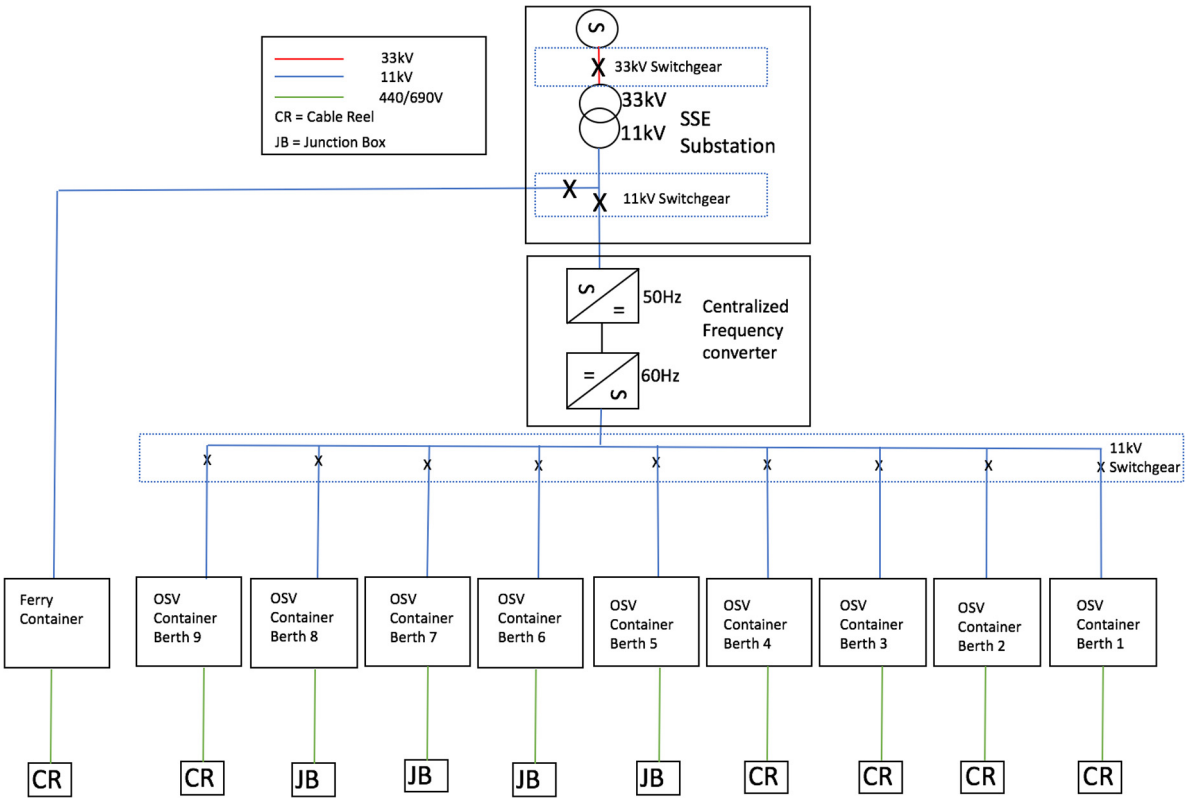

Fig. 3. Final OPS configuration.

necessary equipment (frequency converter, switchgear, low voltage transformers, etc.) or a central frequency converter with individual containerised shore power (OPS) units for each berth. A central unit would easily fit in the area in Regent Quay West meaning that it would only be necessary to install cable reels at the quayside. However, this would require low voltage power to be transported longer distances. The second option was to have a centralized frequency converter with individual OPS units for the OSV berths. This would require a larger footprint taking up space in areas around the port but would use 11 kV distribution. The next step was to calculate approximate cable lengths for each configuration (see Appendix A). It was determined for the centralized OPS unit 13,990 m of cable would be required whereas for the individual OPS units only 4280 m is required, therefore individual OPS units rather than a centralized unit were decided. It would therefore also be necessary to supply one cable dispenser for the ferry terminal, five shore-side cable reels for OSVs and four shore side junction boxes with containerised cable reels.

4.3.4. Final design

After considering the various scenarios, it was decided to opt for the design set out in Figs. 3 and 4. A substation provided by SSE would consist of 33 kV switchgear, a 33/11 kV step down transformer and 11 kV switchgear with separate circuit breakers for the supply to ferry terminal and the centralized frequency converter for the OSV berths, which was not needed for the ferry berth as it requires 50 Hz. The frequency converter chosen is the ACS 6000 SFC unit from ABB. This has been designed specifically for shore power applications. The converter consists of input and output transformers, a 6-pulse three-level IGCT converter and a RC filter. The unit would come complete with a cooling and monitoring system. It would be housed in a converter building which would also include auxiliary distribution, UPS, battery charger, 11 kV switchgear and a master control system. 10 containerized OPS units would be supplied: 9 for OSVs at 60 Hz and 1 for the Ferry Terminal at 50 Hz. Each unit would contain a medium voltage switchgear, a low voltage switchgear and a MV/LV transformer. This would be a Delta to Star configured transformer with a neutral grounding resistor on the secondary side as per the 80005-3 standard. The transformer for the ferry terminal will convert the voltage from 11 kV to 415 V and for the OSV units tappings will be provided on the secondary side of the transformer to supply 440 V or 690 V depending on the requirements of the vessel. The transformer would also be fitted with a pre-magnetization resistor to reduce the inrush current.

4.4. System costs

Table 5 shows the total estimated cost of the project, excluding transportation and civil works. ABB provided a quote for the overall cost for the components. SSE were unable to provide a quote specifically for Aberdeen but provided a cost for a substation of the same size. The cabling quote was also provided by SSE from one of their suppliers. The total cost was calculated as £6.6 m.

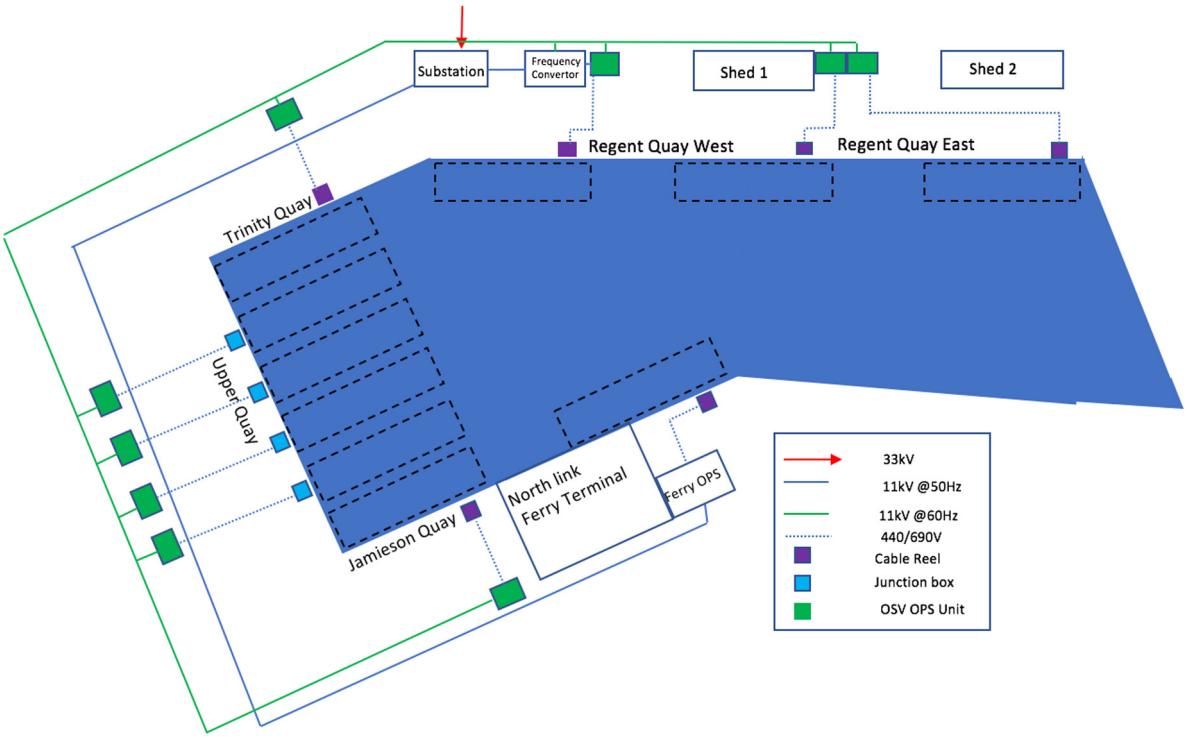

Fig. 4. Individual Onshore Power Supply Units.

Table 5
List of components and total cost.

Description	Cost
Substation	£1,056,000
33 kV/11 kV substation (Including commissioning and civil works)	
33 kV switchgear	
OPS units	£5,500,000
11 kV switchgear 50 Hz (to ferry terminal)	
Static frequency conversion package (including input transformer, converter, output transformer, RC filter and cooling system)	
Shelter for SFC system (including auxiliary distribution, UPS, battery charger)	
11 kV switchgear 60 Hz (1 feeder for distribution switchgear + 1 feeder for RC filter)	
11 kV distribution switchgear for OSVs (9 feeders)	
Shelter for MV distribution Switchgear	
Containerized OPS units (9x OSV @ 60 Hz + 1 x Ferry @ 50 Hz) each including: MV switchgear, MV/LV transformer, pre-magnetization resistor, LV switchgear and neutral grounding resistor	
Cable reels for OSVs	
Junction boxes for inner berths OSVs	
Cable dispenser for ferry	
Master control system	
Master control system commissioning	
Static frequency conversion system commissioning	
Design engineering and project management	
Cabling	£67,676
150 mm^2 3C 11KV SSE Spec cable	
240 mm^2 Aluminium core LV cable	
Polymeric 3C termination kit complete with lugs and boots (150–240 mm^2)	
Total cost of project	£6,623,676
Annual operation and maintenance cost (@ 5%)	£331,184

According to the WPCI, the annual operation and maintenance costs are 5% of the total investment cost of the project (World Ports Climate Initiative, 2016). Other costs are likely such as electrical contracting and interest rates on any loans but these costs have not been considered as this would depend on the rates negotiated.

Table 6
Emissions from MDO/MGO and Scottish grid 2015.

Pollutant	MDO/MGO	Scottish grid 2015
	kg/ton of fuel	g/kWh
CO_2	3206	180.4285
NOx	53.4	0.0750
PM	0665 ($PM_{2.5}$), 0.7 (PM_{10})	0.0034

4.5. Environmental analysis

As discussed, the effectiveness of cold ironing technology relies heavily on the energy mix of the national grid. Scotland has some of the most ambitious renewable energy targets in Europe, aiming to provide 100% of its electricity generation from renewable sources by the year 2020, already achieving 59.4% in 2015. This scenario has also been considered when looking at potential emission savings. Using the WPCI's OPS tool, it was possible to calculate the emissions from this generation mix, shown in Table 6 alongside emissions from MDO/MGO (David Philip McArthur, 2013).

These emission values were used to calculate the ship emissions compared to the equivalent emissions from the grid to establish potential reductions. Table 7 calculates emissions from the same three classes used above: ferries, all OSVs and just the 21 OSVS likely to adopt the technology.

These values were used to examine potential emission savings from the use of OPS with the 2015 energy mix in Scotland and the 2020 target of 100% renewable. Fig. 5 compares emission saving scenarios for different pollutants, according to scenario one (All OSVs and the ferries - blue columns) and scenario two (the 21 OSVs identified and the ferries - red columns).

The UK Government's Department for Environment, Food and Rural Affairs (DEFRA, 2015) have estimated the air quality damage costs from emissions. The figures used for this study are from the average transportation emissions but from the lower sensitivity range (£10,101 per ton of NOx, £45,510 per ton of PM and £8.94 per ton of CO_2). Using these values and the above scenarios, the potential savings to the public were estimated (Table 8). The results show that by installing shore power external costs to the general public can be reduced dramatically, especially if Scotland achieves its target of 100% electricity from renewables by 2020, which could produce £1.3 m in benefits every year if all vessels use shore power, or £0.8 m if only the smaller number of OSVs use it.

4.6. Scenario analysis

Different scenarios were analysed via SCBA to determine if the project could be considered financially feasible based purely on the social costs from environmental savings (Table 9). No income from the vessels is used in the analysis, but it may be that the port would decide to charge a fee to cover some of the operating costs of the system. However, this would depend on whether and how much the port authority invested in the scheme or whether it was fully funded from the Scottish government and/or the EU. Using the preceding results, eight scenarios were calculated, split in three dimensions: whether all vessels used OPS or only the ferries and 21 OSVs identified, whether the environmental savings were calculated on the current electricity production mix or the 2020 goal, and whether the installation benefits from 50% EU capex subsidy, as have some other ports in Europe. The analysis includes both the payback period (undiscounted) as well as the NPV based on the standard UK discount rate of 3.5% with two time periods of 10 and 25 years (see Table 10).

In the worst case scenario (5), where only the Northlink ferries and the 21 identified OSV vessels used OPS, with the current power mix and without subsidy, the payback period was 13.9 years, the NPV was negative over a 10 year period and was £1.2 m over a 25 year period. On the other hand, the best case scenario (4), based on all vessels using the installation, priced at future power mix and with 50% subsidy, was quite positive, with an undiscounted payback period of only 3.5 years and a positive NPV under both timescales.

Table 7
Emissions from ferries and OSVs.

	Ferries	All OSVs	21 OSVs
Fuel consumption (tons)	452.13	1542.76	818.86
Energy Demand (kWh)	2,055,148	6970701.45	3751243.01
Total NOx from ships (tons)	26.32	82.38	43.73
Total NOx from grid (tons)	0.154	0.52	0.28
NOx saved using Shore Power (tons)	26.17	81.86	43.45
Total $PM_{2.5}$ from ships (kg)	300.67	1025.93	544.54
Total PM_{10} from ships (kg)	316.49	1079.93	573.21
Total PM from grid (kg)	6.988	23.84	12.71
PM saved using Shore Power (kg)	610.17	2082.02	1105.04
Total CO_2 from ship (tons)	1449.54	4946.08	2625.28
Total CO_2 from grid (tons)	370.81	1257.71	670.33
CO_2 saved Using Shore Power (tons)	1078.73	3688.37	1954.951

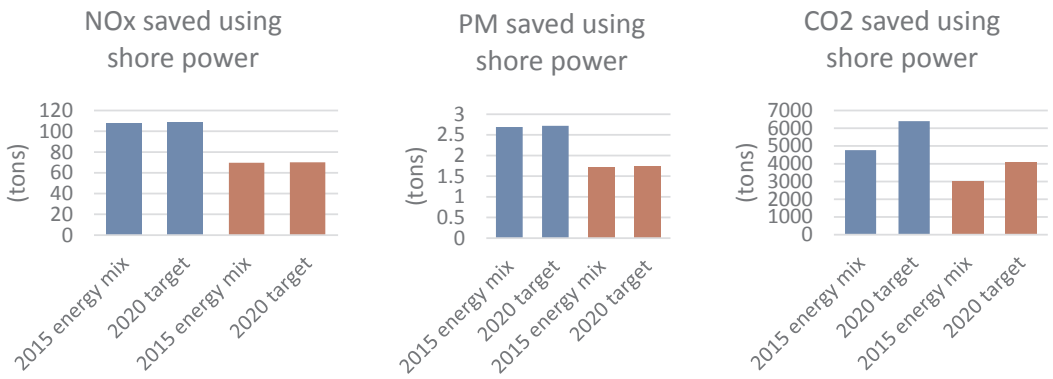

Fig. 5. Nox, PM and CO_2 savings using OPS.

Table 8
Potential annual savings of external costs from emission reduction by using OPS.

Emissions	Scenario 1 (all vessels)		Scenario 2 (ferries + 21 OSVs)	
	2015 energy mix	2020 target	2015 energy mix	2020 target
NOx	£1091,211	£1,097,979	£703,232	£707,575
PM	£122,522	£123,925	£78,277	£79,187
CO_2	£42,618	£57,177	£27,121	£36,429
Total	£1,256,350	£1,279,080	£808,630	£823,191

Table 9
Scenario analysis.

Scenario	Vessels	Energy mix	50% EU subsidy	Payback period in years (undiscounted)	NPV (10 years at 3.5%)	NPV (25 years at 3.5%)
1	All	Current	No	7.2	£1,070,569	£8,624,457
2		Future		7.0	£1,259,605	£8,999,081
3		Current	Yes	3.6	£4,382,407	£11,936,295
4		Future		3.5	£4,571,443	£12,310,919
5	Ferries + reduced group of OSVs	Current	No	13.9	- £2,652,944	£1,245,355
6		Future		13.5	- £2,531,846	£1,485,342
7		Current	Yes	6.9	£658,894	£4,557,193
8		Future		6.7	£779,992	£4,797,180

Table 10
Rated current levels for system.

Rated Voltage	Rated Current*	Permissible voltage drop (5%)
11 kV	52.49A	550 V
690 V	836.74A	34.5 V
440 V	1312.16A	22 V

* S is constant at 1 MV A.

5. Conclusion

It is understandable that the focus in cold ironing research has been on larger ports as these have a higher and more concentrated power demand which results in a simpler installation, a higher reduction of emissions and a shorter payback period. However, if emissions from shipping are to be curbed and if the EU cold ironing target is to be reached then installations in smaller ports for different types of vessels will be necessary. This study has shown that it is feasible to install cold ironing technology in a medium sized port for vessels which are smaller than those traditionally connected to shore power. It was calculated that if all the ships using this area were able to connect to shore power then 108 tons of NOx, 2.7 tons of PM and 4767 tons of CO_2 emissions could be saved annually, equating to £1.3 m of external costs. The system would require considerable financial investment with a cost of approximately £6.6 m; however, in the best case scenario the substantial external cost benefits would return the system capital and operating costs in only 7.0 years, or 3.5 years if subsidised 50% by the EU. This reliance on social benefits to justify the investment explains why

at present the technology has only been implemented in countries where financial support has been offered by governments and other external sources.

Looking at the system design aspects, which were found in the literature to be a major issue, the most efficient system with the least voltage loss was to install individual OPS units for each berth. This would also save costs by reducing cabling requirements. Either way, space is needed on the quay for the sub-station and cable reels. One issue found while designing the project is that four of the berths are difficult to access. It was recommended to use containerised cable reels, however, it is unlikely that these berths would be used for OPS initially and the containerised cable reels could be an additional facility when demand for OPS increases. Similar ports with many small berths will face such challenges, thus the cable design for this study may be transferable to other cases.

In addition to the port investment perspective analysed in this paper, the potential of the system relies on vessel owners saving enough on fuel costs to motivate them to install the onboard technology (see Appendix B for calculations). The study confirmed previous research that ferries have the perfect operating profile for connecting to shore power. These vessels use the terminal regularly for a considerable period of time and have a higher energy demand than the OSVs meaning that the fuel savings would be higher and the payback period would be less, increasing their likelihood to install the onboard connection. However, one of the main issues for the ferries is that they also call in the Orkney and Shetland islands. For the installation of OPS equipment onboard to be cost effective for Northlink the ferries would also want to use it in these ports. However, these islands are small and the local grid may find that the energy demand is too high. One option to counter this would be to have an LNG fuelled generator shore-side to provide electricity to the vessel at those ports as suggested by Sciberras et al. (2014).

The OSVs are significantly more difficult to accommodate. Due to the nature of their work, OSVs are much less predictable. Unlike passenger ships, container vessels and tankers which can often operate the same route for years, OSV contracts take vessels to different areas of the world. If a vessel operating in the North Sea is equipped with OPS equipment then there is a good chance that they can use shore power; however, that same vessel may be given a contract in areas of Africa or Asia where it is very unlikely that OPS facilities will be available any time soon. Given that the OSV operators are already struggling with low contract rates due to the low oil price, it is unlikely that they would be willing to invest in the expensive equipment while the industry is struggling. The recent decline in the oil industry has also acted as a barrier to the uptake of cold ironing (Zis et al., 2016). It is estimated that for OSVs the equipment can cost anywhere between £40,000 and £300,000 per vessel depending on the vessel size (International Maritime Organisation, 2016). If, as shown in the Appendix B, an OSV can save between £9,551 (2015 fuel prices) and £29,362 (if fuel prices were to return to 2008 levels) annually at Aberdeen port alone, not including equivalent savings at other ports, then installing the technology in newer vessels with a suitably long lifetime could become attractive. Additional savings can be obtained by battery hybrid vessels that will require power for hoteling and also for charging the batteries.

All of the 21 vessels identified as potential candidates for OPS were from countries in Northern Europe where (with the exception of the UK) OPS has been installed and supported by national governments. Six of the thirteen companies discussed were from Norway, which has ambitious plans for OPS, having recently launched the ReCharge program, which aims to identify potential ports and ships for OPS and battery hybrid operation. Bergen has already installed an OSV OPS facility and Statoil has supplied funding for seven OSVs to be fitted with batteries and OPS equipment. It is likely that many of these Norwegian vessels will regularly call in Aberdeen Harbour so this could act as an incentive. Other ports, particularly in Northern Europe, are providing similar incentives. The port of Gothenburg does not charge vessels for the electricity, and also offers discounted port dues for vessels with OPS capability. Similarly, the port of Stockholm in Sweden is offering subsidies of up to 1 million Swedish Krone (approximately 100,000 euros) to vessels installing the technology.

Another driver is the 2014/94/EU directive requiring member states to install cold ironing facilities where feasible. This should see several ports in Europe adopt the technology resulting in a drop in the price of the equipment due to economies of scale. It is unclear if the UK will adhere to this directive as it leaves the EU but it is likely that shipping companies in Europe using OPS facilities in other ports will exert pressure for them to be implemented in the UK. A successful implementation of cold ironing in Europe and the USA could also see the IMO encourage other countries to adopt the technology as they have done previously with the sulphur content of fuels. Ports in California, USA that have installed the technology are now requiring vessels calling at those ports to use it, which will further increase uptake. Additionally, while the fuel price is currently low, it is reasonable to believe that stricter regulations could dramatically increase the price of fuel. This has already happened with sulphur limits and an addition of a carbon tax or stricter rules on NOx emissions could see fuel prices increase further thus increasing the cost saving of using OPS.

On the other hand, one challenge arising from stricter regulation is that as vessel efficiencies improve as a result of EEDI and SEEMP, and NOx regulations must be adhered to, then it is likely that emissions from shipping will be reduced and therefore make it more difficult to justify the capital expenditure required for cold ironing. It is also worth considering other emission abatement technologies such as the use of LNG or shore side scrubbers as alternatives as these may be more cost effective and practical for the port to implement. However, if Scotland achieves its 2020 target of producing all electricity from renewable sources then cold ironing would be a completely emission free technology, while LNG is good for local emissions but not for GHG. In combination with LNG-fuelled vessels with battery hybrid capabilities then OPS could still have a significant impact on reducing emissions from shipping.

Appendix A. Cable length calculations

The cables must be correctly sized for transporting power. Lower voltages mean higher currents (Eq. (1)) which require larger cables. The 80005-3 standard requires that the maximum voltage drop allowed is 5% (ISO, IEC and IEEE, 2014). The cables must also comply with the IEE wiring regulations (Institution of Engineering & Technology, 2008).

$$Ir = \frac{Sr}{\sqrt{3}\,.\,Vr} \tag{1}$$

Where:

- Ir = Rated Current (A)
- Sr = Rated apparent power (VA)
- Vr = Rated Voltage (V)

As the low voltage cable will be required to carry both 440 V or 690 V depending on the operating voltage used on board, the vessel calculations were made using only 440 V as this will have the highest current level and be the most difficult to size. For sizing the cables, the IEE regulations must be complied with. The voltage drop and the current per cable limits must not be exceeded.

Table 11 shows the IEE specifications for cable sizing. Using these tables and Eq. (2) the size and number of cables required were calculated. This may require that several cables are run in parallel. 150 mm^2 cable is typically used for 11 kV distribution, as it would be difficult to connect cables with a smaller cross-sectional area to the 11 kV switchgear.

Table 11
Cable specifications.

Conductor cross sectional area (mm^2)	Current carrying capacity (A)	tabulated voltage drop (mV/A/m)
300	261	0.32
240	227	0.37
185	194	0.44
150	170	0.51
120	149	0.61

Institution of Engineering & Technology (2008).

$$Vd = \frac{Z.\,I.\,L}{1000} \tag{2}$$

Where:

- Vd = Voltage drop (V)
- I = Rated current (A)
- Z = tabulated voltage drop (mV/A/m)
- L = Length of cable (m)

Using this information, it was then possible to calculate the cable requirements for the centralized OPS unit and the individual OPS units. It was determined for the centralized OPS unit 13,990 m of cable would be required whereas for the individual OPS units only 4280 m is required. These cable lengths are an approximate measurement, as in practice obstacles might result in longer lengths of cable being required. However, the second option requires considerably less cabling. It also results in less voltage drop and the use of cables with a smaller cross-sectional area. This is significant as the cable trenches required to lay these cables require considerable civil work. Therefore individual OPS units rather than a centralized unit were decided.

Appendix B. The vessel perspective

This paper has analysed the installation from the port perspective, comparing system installation and operating costs against the value of emissions savings. However, as discussed in the conclusion, the potential of the system relies on vessel owners saving enough on fuel costs to motivate them to install the onboard technology. By connecting to shore power while in port this will also reduce the running hours on the auxiliary generators and hence reduce the operation and maintenance costs of the engines. All the ships discussed in Section 4.2 use Marine Gas Oil (MGO) so this is the only type of fuel considered. In the early years of the 21st century many saw cold ironing as a potential method of reducing costs as fuel prices continued to rise; however, with the global financial crash in 2008, demand for shipping dropped which led to fuel prices dropping. As the economy recovered, fuel prices increased. The price then dropped again in 2014 due to an oversupply in the market. Many factors affect the fuel consumption of auxiliary engines such as the type of auxiliary engine, the age, efficiency, etc. For this analysis, average figures from the IMO have been used of 230 g/kWh for engines under 8000 kW and 220 g/kWh over 8000 kW.

Electricity will be provided by the district network operator which for Aberdeen is Scottish and Southern Energy (SSE). There is no set rate for the price of electricity for industrial applications from the provider, so this must be negotiated. However, prices were provided for the BSW Sawmill in Fort William as an example, and the average rate of 4.48p per kWh was used to calculate the expected cost from the network operator. It is likely in the event of the project being approved that lower rates may be negotiated. It may also be possible to apply for a reduced rate of tax on the electricity which has been approved for other cold ironing installations in Europe. The port of Gothenburg even provides the electricity free of charge.

Table 12 presents the results, showing the two ferries at the ferry berth, the total OSVs at the other nine berths, and just the 21 OSVs identified in Section 4.2 as potential candidates for cold ironing. The results show that, at current fuel prices, one OSV is only saving £9551 per year whereas one ferry is saving £52,009 annually. These savings are only a third of what would have been achieved with the 2008 oil price.

Table 12
Fuel and electricity usage and costs.

		Ferry berth	Average for one ferry	All OSVs	21 OSVs	Average for one OSV
Total Energy Demand (kWh)		2,055,149	1,027,575	6,970,701	3,751,243	176,915
Total Fuel Consumption (Tons)		452	226	1543	819	39
Total cost of fuel (£)	At current prices	202,664	101,332	691,526	367,048	17,477
	May 2008	432,393	216,197	1,475,401	783,113	37,288
Total cost of electricity (£)		98,647	49,324	334,594	178,330	7,926
Money saved using shore power (£)	At current prices	104,017	52,009	356,932	188,718	9,551
	May 2008	333,745	166,873	1,140,806	604,783	29,362

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